Forest Research

Missouri
Department of Conservation

Report No. 2

Oak Stump Sprouting in Mature Bottomland Forests at Duck Creek Conservation Area

Forest Research Report No. 2

Oak Stump Sprouting in Mature Bottomland Forests at Duck Creek Conservation Area

by

John Kabrick
Forest Ecologist
Missouri Department of Conservation
1110 S. College Avenue
Columbia, MO 65201

and

Mike Anderson
Forestry District Supervisor
Missouri Department of Conservation
2206 W St. Joseph
Perryville, MO 63775

a report prepared for

The Missouri Department of Conservation
P.O. Box 180
Jefferson City, MO 65102
573/751-4115

2000

ABSTRACT

Kabrick, John and Mike Anderson. 2000. Oak stump sprouting in mature bottomland forests at Duck Creek Conservation Area. Missouri Department of Conservation, Jefferson City, Missouri. Forest Research Report No. 2, 9 pages.

We evaluated the stump sprouting probability, sprout location on the stump, sprout numbers and sprout heights on pin, cherrybark and willow oaks after cutting in closed canopy stands at Duck Creek Conservation Area in Stoddard County, Missouri. A total of eighty dominant, codominant or intermediate canopy class trees were cut in seven, one-acre experimental units distributed among sites having three different soil wetness classes. Species, crown class, diameter at breast height, stump diameter and tree age were recorded prior to cutting. We measured sprout numbers, sprout locations on stump and sprout heights one growing season after cutting. Forty-four percent of stumps sprouted. Willow and cherrybark had the greatest percentage of stumps with sprouts; pin oak had the least. The probability of stump sprouting was negatively correlated with diameter at breast height and was similar to published values of upland white oak. Willow oak on all sites had more sprouts than pin and cherrybark oak. Sprouts on wet sites were half as tall as those on moderately-wet and well-drained sites. Sprouts on both moderately-wet and wet sites were chlorotic and lacked vigor. Future research should focus on stump sprout recruitment and silvicultural practices designed to enhance other forms of oak regeneration.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Oak regeneration is a problem in many of Missouri's bottomland forests and green tree reservoirs. Many of the state's green tree reservoirs contain bottomland oak forests that are over-mature, have closed canopies, little advance oak reproduction and poor acorn production. Advance regeneration, when present, is predominantly non-oak species such as maple and ash that frequently displace oaks after overstory removal.

In upland forests, stump sprouting is an important source of oak regeneration (Johnson, 1992; Sander et al., 1984; Weigel and Johnson, 1998). The contribution of stump sprouts to oak regeneration depends upon stand history, site quality and harvesting methods (Sander et al., 1984; Weigel and Johnson, 1998). In some stands that have been clearcut, stump sprouts may provide many of the oaks that will later grow into dominant or codominant canopy positions (Johnson, 1975; Weigel and Johnson, 1998).

Sprouting may be a viable source of oak regeneration in some bottomland forests (Steele et al., 1992). Many bottomland oak species in Missouri such as pin oak (*Quercus palustris*), cherrybark oak (*Q. pagoda*), willow oak (*Q. phellos*), and swamp white oak (*Q. bicolor*), do sprout from stumps. Pin and willow oak are considered prolific sprouters (McQuilkin, 1990; Schlaegel, 1990). The established root system of oak stumps may enable their sprouts to grow taller faster than recently-germinated oak seedlings and be more competitive with non-oak species. Sprouting may be especially important to oak regeneration where a mature oak overstory exists, but advance reproduction is poor.

Sprouting probabilities are related to site quality, tree age, diameter and species (Johnson, 1992; Weigel and Johnson, 1998). Generally, oak stumps on sites having a higher site index are more likely to sprout than those on sites having a lower site index (Johnson, 1992; Weigel and Johnson, 1998). Sprouting probabilities also decrease with increasing age and diameter (Johnson, 1992; Oliver and Larson, 1996; Weigel and Johnson, 1998). Weigel and Johnson (1998) show that sprouting probabilities for white oaks (*Q. alba*) are generally lower than those of black (*Q. velutina*) and red (*Q. coccinea* and *Q. rubra*) oaks in Indiana.

Shading may affect stump sprouting in some hardwoods (Johnson, 1992), although McGee and Bivens (1984) show no differences in sprouting probabilities among shaded and non-shaded white oak (*Q. alba*) stumps. Gardiner and Helmig (1997) show no differences in first-year survival, sprout numbers, height and basal diameter for water oak (*Q. nigra*) stump sprouts growing in heavily thinned (60% basal area removal) or lightly thinned (40% basal area removal) stands.

We conducted this study to determine the potential role of stump sprouts for bottomland oak regeneration. We evaluated the stump sprouting probability, sprout location on the stump, sprout numbers and sprout heights on pin, cherrybark and willow oaks after one growing season in closed canopy stands at Duck Creek Conservation Area in Stoddard County, Missouri. We hypothesized that sprout numbers and heights would be similar to those of upland oaks.

MATERIALS AND METHODS

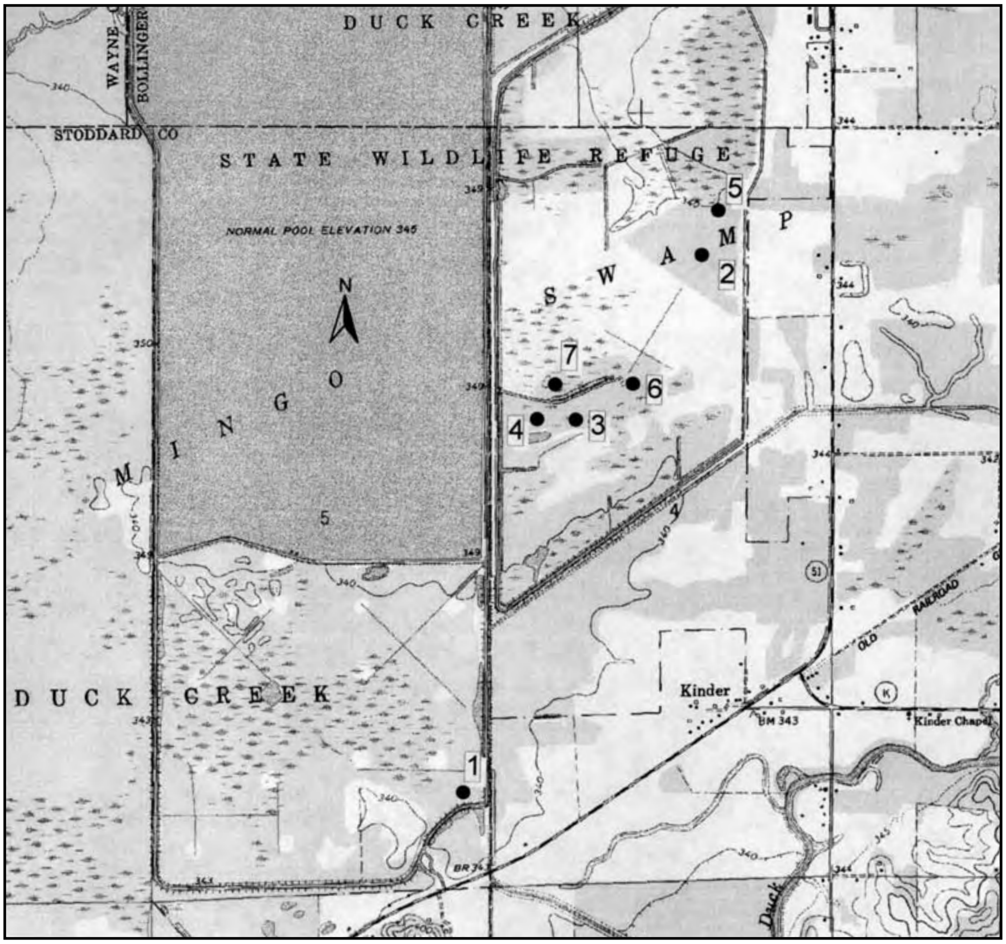

Figure 1. Study area at Duck Creek Conservation Area, Stoddard County, Missouri. Experimental units are numbered 1 through 7.

Study Location and Description

This research was conducted in portions of Pools 2 and 3 at the Duck Creek Conservation Area in Stoddard County near Puxico, Missouri (Figure 1). The hydrology and flooding regimes of the pools are described in detail by Fredrickson (1979) and Hamilton et al. (1991). These pools are generally inundated from the end of September until January. Flooding depths vary within each pool but range from 15 to 51 cm. Pool 2 is inundated 3 out of 5 years to depths of 15 to 35 cm or more, while Pool 3 is flooded annually to a mean depth of 45 cm (Hamilton et al., 1991). Overstory vegetation is mostly pin oak with minor amounts of overcup oak (*Q. lyrata*), American elm (*Ulmus americana*), sweetgum (*Liquidambar styraciflua*), red maple (*Acer rubrum*), willow oak, and cherrybark oak (Hamilton et al., 1991).

Experimental Units and Treatments

Seven to 13 dominant, codominant and intermediate crown class (Smith, 1986) pin, cherrybark and/or willow oaks were cut 4 to 6 inches above ground surface within circular, one-acre experimental units. We found that site wetness varied considerably over short distances within pools during periods when they were not inundated. Because of these differences, we allocated the study sites into three wetness classes: well-drained, moderately-wet and wet. Wet sites were relatively low in elevation and contained several inches of water over two-thirds of the experimental unit at the time of sampling. Moderately-wet sites contained numerous, but small, wet depressions that retained a few inches of water. Well-drained sites occurred on slightly higher elevations that did not retain water. Pin and willow oak were more abundant on wet sites; cherrybark oak was more abundant on well-drained sites.

MATERIALS AND METHODS

There were seven experimental units in this study. Three experimental units were allocated to each of the moderately-wet and wet soil wetness classes. Because there were few well-drained sites that contained sufficient numbers of dominant, codominant or intermediate crown class trees to provide replication, only one treatment unit was allocated to the well-drained site class. Treatments were initiated in April 1998 during the dormant season. Sites were resampled in September 1998 after one growing season.

Measurements

We recorded species, crown class (Smith, 1986), diameter at breast height *(dbh)*, stump diameter and age of each sampled tree. We also noted if sample trees originated as stump sprouts. Although canopy cover was not estimated, canopies of all plots remained relatively closed except for the gaps created by felling candidate trees. After one growing season, we recorded the number of sprouts per stump, sprout locations on each stump and height of the tallest sprout on each stump.

Hypotheses and Analyses

We tested the following null hypotheses:

1. *For stumps that sprouted, there are no differences in sprout numbers or sprout heights among site wetness classes and among species.*

We tested effects of wetness and species by comparing averages.

2. *There are no relationships among sprouting probability and dbh and age.*

This was tested with logistic regression. The Chi-square statistic was used to evaluate the significance of each variable tested. There were insufficient numbers of trees sampled to determine if crown class affected sprouting probabilities.

RESULTS

Forty-four percent of all inventoried stumps sprouted (Table 1). Willow and cherrybark oak had a high percentage of stumps with sprouts (67 and 64%, respectively). Pin oak, despite being known as a prolific sprouter (McQuilkin, 1990), had the fewest stumps with sprouts (35%). Well-drained sites had nearly twice the proportion of stumps with sprouts than moderately-wet sites and more than twice the proportion as wet sites (Table 1). However, we can not determine whether site wetness or differences in species composition caused by site wetness explains these differences. Sprouts on moderately-wet and wet sites appeared chlorotic and lacked vigor compared to those on well-drained sites.

Sprouts that originate at ground level are considered less susceptible to eventual rot than those higher on the stump (Weigel and Johnson, 1998). Roughly 66% of stumps that sprouted had at least one or more stems at ground level (Table 2). Multiple sprouts from a single stump will thin over time, but it cannot be assumed that only ground level sprouts will survive. It is possible that mature trees from sprouts originating higher on the stump will be of poor quality due to rot.

Table 1. Numbers of stumps that sprouted after one growing season by species and soil wetness class.

	---Species---											
	Cherrybark Oak			Pin Oak			Willow Oak			All Species		
Site Wetness Class	# stumps observed	# stumps with sprouts	%	# stumps observed	# stumps with sprouts	%	# stumps observed	# stumps with sprouts	%	# stumps observed	# stumps with sprouts	%
Well-Drained	7	6	86	--	--	--	--	--	--	7	6	86
Moderately-Wet	7	3	43	25	10	40	6	4	67	38	17	45
Wet	--	--	--	32	10	31	3	2	67	35	12	34
All Wetness Classes	14	9	64	57	20	35	9	6	67	80	35	44

Table 2. Numbers of stumps with one or more sprouts originating at ground level after one growing season.

Site Wetness Class	Cherrybark Oak # stumps with sprouts	Cherrybark Oak # stumps with>1 ground sprouts	Cherrybark Oak %	Pin Oak # stumps with sprouts	Pin Oak # stumps with>1 ground sprouts	Pin Oak %	Willow Oak # stumps with sprouts	Willow Oak # stumps with>1 ground sprouts	Willow Oak %	All Species # stumps with sprouts	All Species # stumps with>1 ground sprouts	All Species %
Well-Drained	6	4	67	--	--	--	--	--	--	6	4	67
Moderately-Wet	3	2	67	10	6	60	4	2	50	17	10	59
Wet	--	--	--	10	7	70	2	2	100	12	9	75
All Wetness Classes	9	6	67	20	13	65	6	4	66	35	23	66

The probability of stump sprouting was negatively correlated with dbh (Figure 2). Parent tree age, which ranged from 18 to 76 years, was not a significant factor for explaining sprouting probabilities. However, this data set may be too small to determine the effect of age on stump sprouting. For all species combined, the probability that a stump from a 5-inch dbh tree will sprout was approximately 80%; for a 15-inch tree the probability was <10%. These are similar to sprouting probabilities of upland white oaks in Missouri (Johnson, 1977) and to upland white oaks in Indiana clearcuts (Weigel and Johnson, 1998). These sprouting probabilities are considerably lower than those reported for upland chestnut oak (*Q.prinus*), scarlet oak and northern red oak in Indiana (Weigel and Johnson, 1977) and for scarlet oak in Missouri (Johnson, 1977).

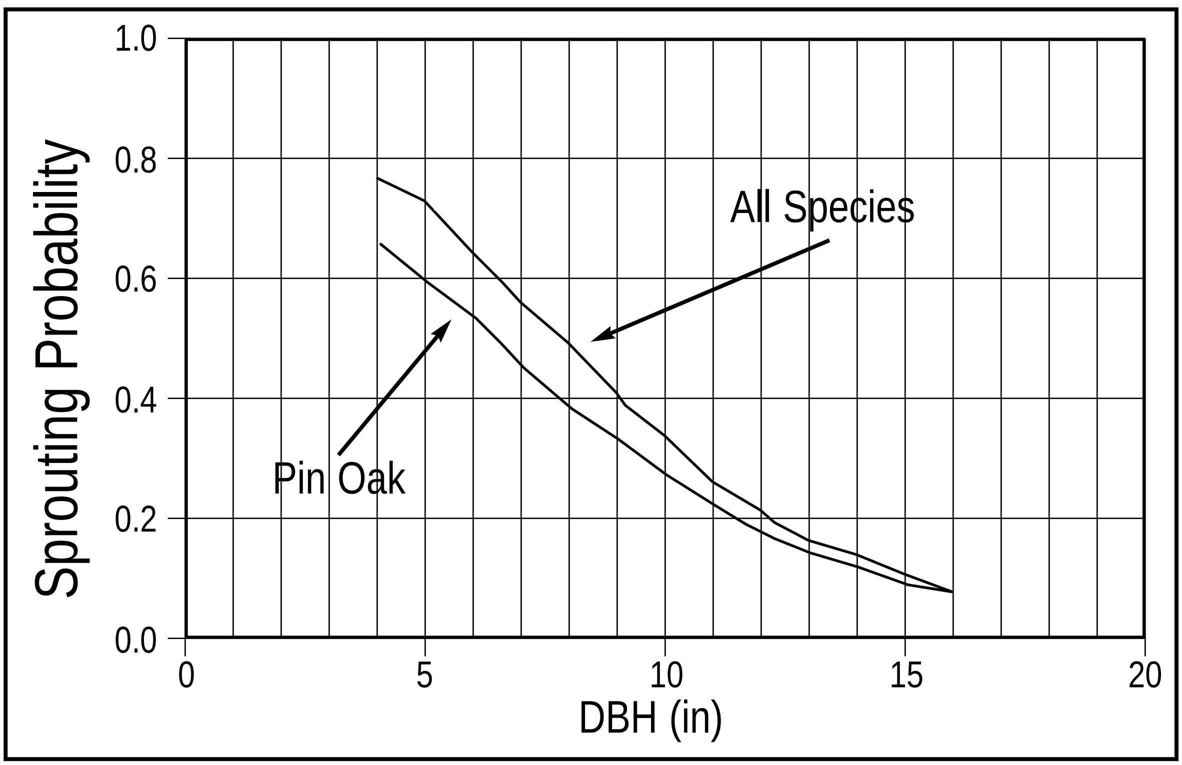

Figure 2. Sprouting probabilities for pin oak, and pin, cherrybark and willow oak (combined) for dominant, codominant or intermediate canopy class trees at Duck Creek Conservation Area.

RESULTS

For stumps that sprouted, there were an average of 13 sprouts per stump (Table 3). Willow oak was the most prolific sprouter having 20 sprouts per stump. Pin oak was the least prolific sprouter having only nine sprouts per stump (Table 3). For all species combined, the tallest sprout per stump averaged 25 inches (Table 4). Cherrybark oak sprouts, on average, were slightly taller than those of the other species.

Site wetness appeared to affect numbers of sprouts and their heights. Well-drained sites had greater numbers of sprouts overall; however, willow oak on wet sites had the greatest numbers of sprouts (Table 3). As stated previously, we can not determine whether site wetness differences or species composition differences caused by site wetness explains differences in sprout numbers. Sprouts on wet sites were considerably shorter than sprouts on moderately-wet and well-drained sites (Table 4). Pin oak stumps on wet sites had fewer and shorter sprouts than stumps on moderately-wet sites. Sprout numbers per stump were similar to those reported for partially shaded water oak in a plantation (Gardiner and Helmig, 1997) but heights were shorter that those reported for partially shaded water oak (Gardiner and Helmig, 1997) and for white oak, black oak and scarlet oak in uplands after harvesting (Johnson, 1977).

Table 3. Average number of sprouts per stump for those with >1 sprout after one growing season.

	---------------------------------Species--------------------------------			
Site Wetness Class	Cherrybark Oak	Pin Oak	Willow Oak	All Species
Well-Drained	16	--	--	16
Moderately-Wet	17	11	16	13
Wet	--	7	28	11
All Wetness Classes	16	9	20	13

Table 4. Average height of the tallest sprout for stumps with >1 sprout after one growing season.

	---------------------------------Species--------------------------------			
Site Wetness Class	Cherrybark Oak	Pin Oak	Willow Oak	All Species
	------- inches --------	------- inches -------	------- inches -------	------- inches -------
Well-Drained	32	--	--	32
Moderately-Wet	23	35	24	30
Wet	--	13	24	15
All Wetness Classes	29	24	24	25

DISCUSSION

Pin, willow and cherrybark oaks at Duck Creek stump sprout readily after dormant season cutting, even under a nearly closed canopy. In closed anopied bottomland forests, these species do not appear to sprout as prolifically as open-grown scarlet and red oak in uplands. Nonetheless, sprouting proportions are similar to those of open-grown upland white oak in Missouri and elsewhere.

Sprouts in wet sites were considerably shorter than in well drained or moderately wet sites. Also, sprouts in moderately-wet and wet sites appeared chlorotic and lacked vigor compared to those on well-drained sites and compared to those that normally occur on upland oak sites throughout Missouri. We attribute this to stressed root systems of the parent trees. Site wetness appears not only to cause overall decline in vigor of standing trees, but also appears to affect the overall height and vigor of their stump sprouts after they are cut.

This study suggests that stump sprouting may play a role in regenerating bottomland pin, willow and cherrybark oak in Missouri's green tree reservoirs. However, stump sprouting may play a smaller role in green tree reservoir oak regeneration than in upland forests because of lower sprout vigor. Future research should focus on assessing recruitment potential of oak stump sprouts. For example, forest openings can be created to determine if stump sprouts in green tree reservoirs will survive and grow to become canopy codominants and/or dominants.

It is important to recognize that even vigorous stump sprouts may not provide all of the desired oak reproduction for stands in green tree reservoirs. In Missouri upland forests, Johnson (1977) shows for most oak species, less that 50% of stems the sizes and ages of those in our study will produce sprouts that will eventually become canopy dominants and codominants five years after cutting. Although data are lacking, there may be less recruitment in green tree reservoirs where oaks are stressed by annual and long-term inundation. Therefore, future research should not only focus on identifying proportions of stumps with sprouts expected to produce codominants and dominants in succeeding stands, it should also focus on silvicultural methods that will enhance other forms of oak reproduction. Green tree reservoirs provide unique opportunities to adjust impoundment frequencies and durations in conjunction with silvicultural methods to enhance oak regeneration success.

This research also suggests that in future studies, experimental units should continue to be stratified by site wetness classes. Site wetness appeared to affect species composition, sprout heights and sprout vigor. Site wetness differences may also affect responses to silvicultural treatments.

SUMMARY

- At Duck Creek, pin oaks, willow oaks and cherrybark oaks in closed canopy stands had stump sprout probabilities similar to those of open-grown upland white oak.
- Stump sprouts, especially in wet or moderately-wet sites, were less vigorous and shorter than those observed in Missouri's upland forests or reported elsewhere.
- Stump sprouting at Duck Creek may play a smaller role in oak regeneration than in Missouri's upland forests because of poor sprout vigor.

DATA SET

Plot	Moisture	Tree Tag#	Species	Crown Class	DBH (in)	Stump Dia (in)	Age	Sprouted Before?	No. Sprouts	Ht. Tallest	Origin
1	Mod-wet	1	pin oak	Codominant	12.8	17.0	45	y	9	3	collar only
1	Mod-wet	2	pin oak	Intermediate	8.0	10.9	40	n	20	37	ground
1	Mod-wet	3	pin oak	Dominant	11.0	15.0	34	n	0	0	none
1	Mod-wet	4	pin oak	Codominant	12.6	16.7	35	n	0	0	none
1	Mod-wet	5	pin oak	Intermediate	12.1	17.3	76	n	0	0	none
1	Mod-wet	6	pin oak	Codominant	10.2	15.2	48	n	20	28	ground
1	Mod-wet	7	pin oak	Intermediate	12.8	13.7	18	n	2	49	ground
1	Mod-wet	8	pin oak	Intermediate	13.4	15.1	54	n	0	0	none
1	Mod-wet	9	pin oak	Intermediate	7.6	10.2	49	n	16	34	ground
1	Mod-wet	10	pin oak	Intermediate	9.5	15.6	44	y	0	0	none
1	Mod-wet	11	pin oak	Intermediate	7.0	11.2	41	n	0	0	none
1	Mod-wet	12	pin oak	Intermediate	13.0	17.2	49	n	5	23	collar only
1	Mod-wet	13	pin oak	Intermediate	13.9	17.3	50	n	0	0	none
2	Mod-wet	14	pin oak	Intermediate	9.0	18.5	40	n	0	0	none
2	Mod-wet	15	pin oak	Codominant	10.4	15.0	39	n	0	0	none
2	Mod-wet	16	pin oak	Intermediate	12.2	15.2	47	n	0	0	none
2	Mod-wet	17	pin oak	Intermediate	9.4	14.6	47	n	3	20	collar only
2	Mod-wet	18	pin oak	Intermediate	16.1	18.0	51	n	0	0	none
2	Mod-wet	19	pin oak	Intermediate	10.8	13.9	42	n	0	0	none
2	Mod-wet	20	willow oak	Intermediate	9.3	12.5	53	n	0	0	none
2	Mod-wet	21	pin oak	Codominant	14.0	18.2	48	n	0	0	none
2	Mod-wet	22	willow oak	Intermediate	8.3	12.8	52	n	6	20	collar only
2	Mod-wet	23	chrybk oak	Intermediate	10.7	14.7	54	n	0	0	none
2	Mod-wet	24	chrybk oak	Intermediate	13.7	19.3	51	n	0	0	none
2	Mod-wet	25	pin oak	Codominant	8.5	12.9	47	n	0	0	none
3	Wet	26	pin oak	Intermediate	6.4	9.9	43	n	1	8	not determined
3	Wet	27	pin oak	Intermediate	10.2	16.8	64	n	0	0	none
3	Wet	28	pin oak	Codominant	9.3	12.0	41	n	0	0	none
3	Wet	29	pin oak	Intermediate	12.0	15.7	56	n	0	0	none
3	Wet	30	pin oak	Intermediate	7.4	12.1	44	n	0	0	none
3	Wet	31	pin oak	Intermediate	9.9	12.5	60	y	0	0	none
3	Wet	32	pin oak	Codominant	10.2	13.7	55	n	0	0	none
3	Wet	33	pin oak	Dominant	12.9	16.6	60	n	0	0	none
3	Wet	34	pin oak	Codominant	10.8	16.7	64	y	0	0	none
3	Wet	35	pin oak	Intermediate	5.0	6.8	44	n	0	0	none
3	Wet	36	pin oak	Codominant	8.9	15.5	47	n	0	0	none
4	Wet	37	pin oak	Intermediate	6.2	8.5	42	n	0	0	none
4	Wet	38	pin oak	Intermediate	6.8	11.8	48	n	0	0	none
4	Wet	39	pin oak	Codominant	9.3	13.8	46	n	15	24	ground
4	Wet	40	pin oak	Intermediate	6.8	9.1	48	n	3	16	collar only
4	Wet	41	pin oak	Intermediate	4.0	5.9	44	n	16	12	ground
4	Wet	42	pin oak	Intermediate	8.5	11.7	50	n	0	0	none
4	Wet	43	willow oak	Intermediate	9.0	12.5	52	n	0	0	none
4	Wet	44	pin oak	Codominant	8.0	16.8	58	n	1	10	ground
4	Wet	45	pin oak	Codominant	9.8	12.0	50	n	0	0	none
4	Wet	46	pin oak	Intermediate	5.0	7.4	41	n	7	7	ground
4	Wet	47	pin oak	Intermediate	4.1	6.2	31	n	7	18	ground
4	Wet	48	pin oak	Intermediate	6.2	13.1	44	n	1	4	not determined
5	Mod-wet	*50	pin oak	Intermediate	7.2	11.0	42	n	5	33	collar only

DATA SET

Plot	Moisture	Tree Tag#	Species	Crown Class	DBH (in)	Stump Dia (in)	Age	Sprouted Before?	No. Sprouts	Ht. Tallest	Origin
5	Mod-wet	51	chrybk oak	Intermediate	4.6	6.2	42	n	7	23	ground
5	Mod-wet	52	willow oak	Codominant	8.9	13.8	42	n	4	18	ground
5	Mod-wet	53	willow oak	Intermediate	9.8	13.2	46	n	6	35	collar only
5	Mod-wet	54	chrybk oak	Intermediate	7.3	10.9		y	26	28	not determined
5	Mod-wet	55	pin oak	Intermediate	8.0	10.9	40	n	20	37	ground
5	Mod-wet	56	pin oak	Intermediate	6.7	9.8	42	n	24	54	ground
5	Mod-wet	57	chrybk oak	Intermediate	7.8	12.4	47	n	0	0	none
5	Mod-wet	58	willow oak	Intermediate	5.3	7.5	42	n	49	23	ground
5	Mod-wet	59	chrybk oak	Codominant	8.5	12.1	49	n	0	0	none
5	Mod-wet	60	willow oak	Codominant	8.2	13.1	46	n	0	0	none
5	Mod-wet	61	pin oak	Codominant	9.7	14.0	50	n	0	0	none
5	Mod-wet	62	chrybk oak	Codominant	7.7	12.6	43	n	17	17	ground
6	Dry	63	chrybk oak	Intermediate	6.5	9.0	39	n	21	50	ground
6	Dry	64	chrybk oak	Intermediate	5.9	8.5	40	n	61	39	ground
6	Dry	65	chrybk oak	Codominant	8.4	12.3	52	n	2	47	not determined
6	Dry	66	chrybk oak	Intermediate	8.3	13.5	48	n	0	0	none
6	Dry	67	chrybk oak	Intermediate	5.5	8.7	39	n	4	34	ground
6	Dry	68	chrybk oak	Dominant	12.2	16.4	64	n	8	13	ground
6	Dry	69	chrybk oak	Dominant	11.6	16.2	52	n	2	10	not determined
7	Wet	70	pin oak	Intermediate	10.8	15.4	57	n	0	0	none
7	Wet	71	pin oak	Intermediate	3.8	5.1	20	n	0	0	none
7	Wet	72	pin oak	Intermediate	8.5	12.5	55	n	0	0	none
7	Wet	73	pin oak	Intermediate	6.6	8.7	42	n	0	0	none
7	Wet	74	pin oak	Intermediate	6.8	10.1	39	n	0	0	none
7	Wet	75	pin oak	Intermediate	6.2	10.0	43	n	0	0	none
7	Wet	76	pin oak	Intermediate	7.7	11.4	45	n	0	0	none
7	Wet	77	pin oak	Intermediate	4.2	7.7	21	n	18	12	ground
7	Wet	78	pin oak	Intermediate	9.5	12.5	37	n	0	0	none
7	Wet	79	willow oak	Intermediate	4.9	7.6	27	n	7	24	ground
7	Wet	80	willow oak	Intermediate	4.0	6.2	26	n	48	24	ground
7	Wet	81	pin oak	Codominant	9.1	13.0	51	n	4	20	ground

* There was no tree tagged as #49.

REFERENCES

Fredrickson, L.H. 1979. Floral and faunal changes in lowland hardwood forests in Missouri resulting from channelization, drainage, and impoundment. USDA-Fish and Wildl. Serv. Res. Publ. 148. 29 pp.

Gardiner, E.S. and L.M. Helmig. 1997. Development of water oak stump sprouts under a partial overstory. New Forests. 14:55-62.

Hamilton, D.A., T.G. Kulowiec, and S.L. Sheriff. 1991. Regeneration of bottomland oaks at Duck Creek Wildlife Area. Study No. 84. Missouri Department of Conservation. 49 pp.

Johnson, P.S. 1975. Growth and structural development of red oak sprout clumps. Forest Science. 21:413-418.

Johnson, P.S. 1977. Predicting oak stump sprouting and sprout development in the Missouri Ozarks. Res. Pap. NC-149. St. Paul, MN: United States Department of Agriculture, Forest Service, North Central Experiment Station. 9 pp.

Johnson, P.S. 1992. Sources of oak reproduction. In: Loftis, D.L. and C.E. McGee (eds.) Symposium proceedings, Oak regeneration: Serious problems, practical solutions. September 8-10, 1992. Knoxville, TN. Gen. Tech. Rep. SE-84. Asheville, NC: United States Department of Agriculture, Forest Service, Southeastern Forest Experiment Station: 112-131.

McGee, C.E. and D.L. Bivens. 1984. A billion overtopped white oak - assets or liabilities? Southern Journal of Applied Forestry. 8:216-220.

McQuilkin, R. A. 1990. Pin oak. In: R.M. Burns and B.H. Honkala (eds.) Silvics of North America, Vol. 2, Hardwoods. United States Department of Agriculture, Forest Service. Agriculture Handbook 654.

Oliver, C.D. and B.C. Larson. 1996. Forest stand dynamics. Undated Edition. John Wiley and Sons, New York. 520 pp.

Ross, M.S., T.L. Sharik, and D.W. Smith. 1986. Oak regeneration after clear felling in southwest Virginia. Forest Science. 32:157-169.

Sander, I.L., P.S. Johnson, and R. Rogers. 1984. Evaluating oak advance reproduction in the Missouri Ozarks. Res. Pap. NC-251. St. Paul, MN: United States Department of Agriculture, Forest Service, North Central Experiment Station. 11 pp.

Schlaegel, B.E. 1990. Willow oak. In: R.M. Burns and B.H. Honkala (eds.) Silvics of North America, Vol. 2, Hardwoods. United States Department of Agriculture, Forest Service. Agriculture Handbook 654.

Smith, D.M. 1986. The practice of silviculture. Eighth ed. John Wiley and Sons, New York.

Steele, W.B., D.D. Hook, M.A. Buford, and J.G. Williams. 1992. Enhancing oak regeneration in a mixed bottomland hardwood stand after a major disturbance. pp 87-90, In: J. Brishette (ed.) Proceedings of the Seventh Biennial Southern Silvicultural Research Conference. November 17-19, 1992. Mobile, AL. Gen. Tech. Rep. SO-93. New Orleans, LA: United States Department of Agriculture, Forest Service.

Weigel, D. R. and P.S. Johnson. 1998. Stump sprouting probabilities for southern Indiana oaks. Tech. Brief TB-NC-7. St. Paul, MN: United States Department of Agriculture, Forest Service, North Central Experiment Station. 6 pp.

CONSERVATION DEPARTMENT

MISSOURI